Alternative Land Use Policies: Real Options with Costly Reversibility

Feng Song
Dept. of Agricultural, Food, and Resource Economics
DOE Great Lakes Bioenergy Research Center
Michigan State University, East Lansing, MI 48824-1039, USA.
songfeng@msu.edu

Jinhua Zhao
Dept. of Economics and Agricultural, Food, and Resource Economics,
Michigan State University, East Lansing, MI 48824-1039, USA.
jzhao@msu.edu

Scott M. Swinton
Dept. of Agricultural, Food, and Resource Economics
DOE Great Lakes Bioenergy Research Center
Michigan State University, East Lansing, MI 48824-1039, USA.
swintons@msu.edu

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Abstract

This paper adopts a real options framework to evaluate the cost-effectiveness of four types of subsidies that aim to encourage a socially desirable land use under return uncertainties and costly reversibility of land use change. We first present a land conversion model to show how the subsidies that are expected net present value (ENPV) equivalent can change a representative farmer's optimal land conversion rules differently for converting land into an alternative use as well as converting out of it. This is because these subsidies affect the land conversion costs, land return level and uncertainty differently. Then in the context of encouraging energy crop production, we compare the probabilities of inducing the representative farmer to convert land from a current crop to an energy crop across four subsidies for the same, fixed 30-year expected government budget. Results of Monte Carlo simulations show that the insurance subsidy results in the highest probability of land being converted to the energy crop, followed by the constant subsidy. Although the cost-sharing subsidy and the variable subsidy encourage land conversion to the energy crop, they also reduce the incentive to retain land in it. Over time, these two subsidies have little effect on the probability of land converting into energy crops compared to the no-subsidy baseline. Combining the establishment cost-sharing subsidy with other annual subsidies has no added effect over single subsidies in inducing land conversion to the energy crop.

Key words: agricultural subsidies, cost-effectiveness, two-way land conversion, real options, Monte Carlo simulations

JEL codes: Q24, Q48

Alternative Land Use Policies: Real Options with Costly Reversibility

Agricultural subsidies have been used to induce socially desirable land uses for a long time. An example is the U.S. Conservation Reserve Program, in which farmers set aside production land to provide environmental benefits and receive payments from government in return. One strategy to mitigate climate change proposed in the United States and Canada is subsidizing farmers to convert the marginal agricultural land to forest for more carbon sequestration (Stavins 1999; McKenney et al. 2004; Lubowski, Plantinga, and Stavins 2006). A body of literature has analyzed the effects of subsidies on the land use change, such as Stavins and Jaffe (1990) and Plantinga, Mauldin and Miller (1999). A common assumption in these literature is that a farmer will compare the expected net present value (ENPV) of returns to different land uses and choose the one with the highest ENPV. Thus subsidizing a desirable land use will raise its return and induce land converted to it. ENPV decision rule implies that the form of the subsidy, such as lump sum or continuous, constant or variable, does not matter. Subsidies that are equal under the ENPV rule are implicitly assumed to give farmers the same incentive to convert land to the desirable use.

It has been observed that farmers often do not convert land even it is profitable to do so under the ENPV rule (Isik and Yang 2004; Plantinga et al. 2002). Parks (1995) explained land conversion hysteresis as a consequence of *risk aversion* and expected capital gains. He also explored the effects of some types of conversion subsidies. Although not explicitly clear, in his model a cost-sharing subsidy and a constant annual rental payment that do not change the uncertainties of land return can give a farmer the same conversion incentive if their annualized values are equal. In contrast, the real options framework shows that the interaction among irreversible sunk cost, uncertainty, and learning can cause even *risk-neutral* farmers to be more reluctant to convert land uses than the NPV rule predicts (e.g., Titman 1985). More importantly, subsidies taking various forms can affect the conversion costs, the level and uncertainty of land use returns differently. Subsequently they will affect the farmers' land conversion decision differently even though they are ENPV-equivalent.

The purpose of this paper is to compare the long term effectiveness of different forms of agricultural subsidies in achieving an increase in a desired land use when farmers are risk neutral. We adopt an innovative real options approach by relaxing the absolute irreversibility assumption in previous literature and allowing for land use conversion in two directions. A farmer deciding on converting to another land use is allowed to take into consideration the future possibility of converting the land back to its original use under plausible market conditions. The absolute irreversibility assumption might be reasonable for urban development (Capozza and Li 1994; Abebayehu, Keith, and Betsey 1999). However for agricultural land, a farmer can switch between different uses with costs. Allowing two-way land conversion can help capture the flexibility of farmer's land use decisions. Moreover, it has important implications in designing subsidy programs since the subsidies not only change the farmer's willingness to convert land into the desirable use but also the willingness to convert it out.

To make our ideas concrete, we evaluate land conversion subsidies in the context of encouraging production of energy crops, which can be directly combusted to provide electricity or converted to transportation fuel. Globally the market demand for energy crops is largely driven by various renewable energy policies. For example, in the United States, more than 20 states mandate Renewable Portfolio Standards (RPS), which require a certain minimum quantity of electricity produced from eligible renewable energy sources. Biomass is an eligible energy source in some states. But more (potential) demand for energy crops may come from cellulosic biofuel production. Currently liquid biofuels are strongly advocated in many countries, including the United States, due to political concerns related to energy security, climate change and rural development (Khanna 2008 ; Rajagopal and Zilberman 2007). Although grain-based biofuel currently dominates the market, cellulosic biofuel is believed to have superior environmental performance, such as higher net energy, higher carbon credit and more-environmental friendly-feedstocks (Schmer et al. 2008; Paine et al. 1996). For this reason, the U.S. Energy Independence and Security Act (EISA) of 2007 mandates the use of cellulosic ethanol, increasing from 0.1 billion gallons annually in 2010 to 16 billion gallons in 2022. To meet this mandate, significant expansion of energy crops is expected to occur on agricultural land and compete with traditional crops for the limited acres (Thomson et al. 2008; Walsh et al. 2003).

Coupled with energy policies that induce energy crop production through creating new markets for them, many countries also use agricultural subsidies to provide direct production incentives. The perennial nature of most energy crops involves sunk costs to establish the plants, which may become prohibitively high for some woody crops. To overcome this barrier, a lump-sum payment is often provided to cover the establishment costs in full or partial. In the 1990s, Sweden offered 10,000SEK/ha (roughly $573/acre) establishment subsidy for planting willow (Helby, Rosenqvist, and Roos 2006). In early

2007, the Irish government announced it would subsidize half of the establishment costs for willow and miscanthus (Styles, Thorne, and Jones 2008). In the United States, the Food, Conservation and Energy Act (FCEA) of 2008 introduced direct payments for up to 75% of establishment costs for eligible energy crops. In addition to a cost-sharing subsidy to help start-up, annual payment is also provided to support production, collection, harvest, storage and transportation of energy crops. For example, European Union (EU) farmers can receive an annual payment of €45/ha (roughly $25/acre) for growing energy crops on production land (Rajagopal and Ziberman 2007). The Irish government subsidizes additional €85/ha (about $45/acre) for growing willow and miscanthus (Styles, Thorne, and Jones 2008). In contrast, the U.S. farmers can receive a payment to cover costs of harvest, storage and transportation that is equal to what they obtain from biorefiners for 2 years (up to $45/ton). This type of subsidy will vary with the market price and yield of biomass. FCEA also required the Federal Crop Insurance Cooperation to study the insurance policies for energy crops, providing the future possibility of subsidizing the energy crops insurance. Given that large subsidy amounts are spent and take different forms, the effectiveness of these subsidies should be systematically evaluated.

Our paper contributes to the literature in several aspects. First, we examine a range of ENPV-equivalent subsidies, showing how they can affect a representative farmer's optimal land conversion rule differently, depending on their effects on the conversion costs, returns level and variability of returns. Second, we examine how optimal land conversion strategies differ between a real options framework assuming irreversible land use decisions and our framework, which allows reversion to a prior land use. In this framework, it turns out that subsidies not only change the farmer's willingness to convert land into energy crops but also the willingness to convert back out. Third, based on this improved model, we compare the effectiveness of subsidy programs for encouraging the production of energy crops.

The remainder of the paper is organized as follows. In the next section, we present a general land conversion decision model without governmental intervention to better expose the idea of uncertainty and sunk costs causing hysteresis in land conversion. Next, we examine how various forms of subsidies for energy crops can change a representative farmer's land conversion decision rule differently even though they are ENPV-equivalent. Then we perform a Monte Carlo simulation on the farmer's annual land use choice under each type of subsidy over a period of 30 years. The subsidy levels are calibrated so that they have the same expected cost to the governmental and their long-term performances are compared according to the increased expected conversion rate into energy crops than no subsidy support. Finally we give results and conclusions.

Land Conversion Decision Model

Decision without Governmental Intervention

Consider a representative, risk neutral farmer with a unit of land facing two competing crop production alternatives: a corn-soybean rotation and switchgrass, which are selected as representative of a traditional crop and an energy crop. The returns to corn-soybean and switchgrass at period *t* are denoted by $\pi_{cs}(t)$ and $\pi_{sw}(t)$, respectively. The farmer can convert land from corn-soybean to switchgrass with a lump-sum cost C^{cs} or vice versa with a lump-sum cost C^{sw}. The farmer seeks to maximize the net present value of current and future returns at a discount rate r over an infinite time horizon. The future returns to corn-soybean and switchgrass are assumed to evolve according to the geometric Brownian motion (GBM) [1]:

(1) $d\pi_i = u_i \pi_i dt + \sigma_i \pi_i dz_i \qquad\qquad i \in \{cs, sw\}$

where dz_i is the increment of a Wiener process. The correlation coefficient of the two return processes is ρ, i.e., $E(dz_{cs} dz_{sw}) = \rho dt$. Traditional crop and energy crop returns could be correlated for a variety of reasons, e.g. both are linked with energy prices and are subject to macro-economic shocks.

According to the ENPV decision rule, the farmer will switch from one crop to another when the ENPV of switching is higher than staying, i.e.,

(2) Convert if $E\int_0^\infty \pi_j(t) e^{-rt} dt - C^i \geq E\int_0^\infty \pi_i(t) e^{-rt} dt \qquad i, j \in \{cs, sw\}$, and $i \neq j$

The real options literature has pointed out that the ENPV approach ignores that the agent can optimally postpone their actions due to the irreversibility and uncertainty of future returns. Next we derive the optimal decision using real options approach. Let $V^i(\pi_{cs}, \pi_{sw})$ be the value function of currently being in land use *i*, which is defined as the expected net present value of all future returns starting from corn-soybean and then following optimal policies. Due to the option of converting into use $j \neq i$, the payoff depends on the distribution of future returns of *both* land uses, the information for which is contained in the two current returns, $\pi_{cs}(t)$ and $\pi_{sw}(t)$. At time *t*, the farmer chooses between keeping the land in use *i* and converting it into alternative use *j*:

[1] We drop off the time t to simplify the notation whenever it does not cause confusion.

(3)

$$V^i(\pi_{cs},\pi_{sw}) = \max\left\{\pi_i(t)dt + e^{-rdt}EV^i(\pi_{cs}(t+dt),\pi_{sw}(t+dt)),\ V^j(\pi_{cs}(t),\pi_{sw}(t)) - C^i\right\}$$

The first term on the right hand side describes the payoffs if the land is kept in use *i*: in the infinitesimal period $[t, t+dt]$, the farmer receives profit from land use *i* at rate $\pi_i(t)$, and at the end of the period, receives the new *discounted expected* payoff $e^{-rdt}EV^i(t+dt)$. The second term on the right hand side describes the payoff if the land is converted into use *j*: the farmer receives the expected payoff of use *j*, $V^j(t)$, but incurs the conversion cost C^i.

Intuitively, the conversion decision will depend on the relative returns of the two competing crops. For example, for any return level of π_{cs}, there will be a critical value π_{sw}^* with which continuing in corn-soybean is optimal if $\pi_{sw} < \pi_{sw}^*$ and conversion is optimal if $\pi_{sw} > \pi_{sw}^*$. The $\pi_{sw}^*(\pi_{cs})$ will form a critical conversion boundary in the $\pi_{cs} - \pi_{sw}$ space. Similarly, there is another conversion boundary from switchgrass to corn-soybean $\pi_{cs}^*(\pi_{sw})$. Following the standard procedures of solving the real options problems, we can characterize the optimality conditions of our land conversion decision. In the continuation region (where the agent continues in current land use), the value functions need to satisfy the following the equation:

(4) $$rV^i(\pi_{cs},\pi_{sw}) = \pi_i + \sum_i \alpha_i\pi_i V^i_{\pi_i} + \sum_i 1/2\sigma_i^2\pi_i^2 V^i_{\pi_i\pi_i} + \rho\sigma_1\sigma_2\pi_{cs}\pi_{sw}V^i_{\pi_{cs}\pi_{sw}}$$

This is a no-arbitrage condition expanded by Ito’s lemma, implying that the rate of return of investing V^i dollars (left-hand side) should be equal to the rate of return generated by land use *i* (right-hand side). On the boundaries of conversion, the payoffs of continuing in the current use should be equal to the payoffs of converting minus the conversion costs, along with their derivatives. These are the value-matching and smooth-pasting conditions:

(5) $V^i(\pi_{cs}, \pi_{sw}) = V^j(\pi_{cs}, \pi_{sw}) - C^i$ when $\pi_i = \pi_i^*(\pi_j)$ $i, j \in \{cs, sw\}$, and $i \neq j$

(6) $$\frac{\partial V^i(\pi_{cs}, \pi_{sw})}{\partial \pi_{cs}} = \frac{\partial V^j(\pi_{cs}, \pi_{sw})}{\partial \pi_{cs}} \text{ and}$$

$$\frac{\partial V^i(\pi_{cs}, \pi_{sw})}{\partial \pi_{sw}} = \frac{\partial V^j(\pi_{cs}, \pi_{sw})}{\partial \pi_{sw}} \quad \text{when } \pi_i = \pi_i^*(\pi_j)\ i, j \in \{cs, sw\}, \text{and } i \neq j$$

The system of equations (4)-(6) subject to (1) implicitly defines the unknown value functions and two conversion boundaries. A key insight of the real options approach is that when the land is in use *i*, say in traditional crops, the farmer has the *option* of converting it into energy crops when market conditions are "favorable." Once converted, it is costly to revert back to traditional crops if the market conditions turn out to be less favorable. Thus, sticking to the current land use (in traditional crops) has an additional value, called option value, derived from the option of converting it into the alternative use (in energy crops). But since the land in energy crops can be further converted back to traditional crops (albeit at a cost), the option value of converting from traditional crop to energy crops further depends on the option value associated with converting in the other direction, from energy crop to traditional crops. The mutual dependence of the two option values significantly complicates the solution algorithm. Except in special cases, such as when value functions are homogeneous of degree one, there is no analytical solution to (4)-(6). Instead, we solve the model numerically using the collocation method (Miranda and Fackler 2002; Fackler 2004). This method approximates the unknown value functions using a linear combination of *n* known basis functions and fixes the coefficients by solving a system of *n* equations that are derived from the optimality conditions (4)-(6). Appendix A provides more details.

Table 1 presents the parameters we use to solve the model. More details about the parameter estimation are documented in the first essay (Song, Zhao, and Swinton 2010). In summary, historical data on corn and soybean returns were obtained from the U.S. Department of Agriculture (USDA), while data on switchgrass returns were constructed from historical ethanol prices and production cost that are taken from various sources. The drift parameters and variance parameters of the two crop return series were econometrically estimated. The land conversion costs were taken from literature (Khanna, Dhungana, and Clifton-Brown 2008; Williams et al. 2009). We assume that the two returns have a correlation coefficient of 0.3, instead of -0.3 as estimated in essay 1. Historical returns to corn-soybean and switchgrass could be negatively correlated as indicated by our estimation results. Part of the reason is that switchgrass revenue is simulated as a function of petroleum price and thus highly positively correlated with petroleum, whereas until 2005, corn-soybean returns were negatively correlated with petroleum prices due to petroleum used as transportation and fertilizer inputs. However, this pattern of negative correlation could change as more corn and soybean are used to produce biofuels, and as agricultural and petroleum markets become more integrated. Then high petroleum prices may push up corn and soybean prices, increasing their returns. A supporting evidence is that the correlation between the annual ethanol price and corn-soybean return for year 1982-2005 is -0.07, and it changes to 0.28 for year 2006-2008. Tyner (2009) shows similar result that the price correlation between crude oil and corn change from -0.29 during period 1988-2005 to 0.8 during period 2006-2008. Furthermore, the positive correlation may become stronger as switchgrass or other energy crops expand production and compete with corn-soybean for limited land.

Figure 1 shows the two boundaries for conversions from corn-soybean to switchgrass (b^{C-S}) and from switchgrass to corn-soybean (b^{S-C}). The two boundaries divide the $\pi_{cs} - \pi_{sw}$ space into three regions. Above the boundary b^{C-S}, it is optimal to convert from corn-soybean to switchgrass. Below the boundary b^{S-C}, it is optimal to convert from switchgrass to corn-soybean. Between the two boundaries, it is optimal to keep land in its current use. The large inaction zone indicate significant hysteresis in land conversion decisions. For instance, the calculated switchgrass returns based on 2009 prices is \$133/acre while the corn-soybean return in 2008 is \$119/acre (both in 1982 dollars).[2] If the land is currently in corn-soybean, the minimum switchgrass return for converting the land to switchgrass is $b^{C-S}(119) = \$345$/acre, which is significantly higher than the \$ 204/acre threshold value under ENPV rule.[3] Thus, the land will be kept in a corn-soybean rotation even though $\pi_{sw} > \pi_{cs}$. Conversely, if the land is already in switchgrass, the required minimum corn-soybean return for converting into corn-soybean is about \$ 260/acre. Thus, the land currently in switchgrass will not be converted either.

Decision under Different Subsidies

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[2] 2009 corn and soybean returns are not available yet from USDA.

[3] The conversion boundaries under ENPV are: $b_{NPV}^{C-S}(\pi_{cs}) = \pi_{cs}\dfrac{r-\alpha_{sw}}{r-\alpha_{cs}} + (r-\alpha_{sw})C^{cs}$ for conversion from corn-soybean to switchgrass, and $b_{NPV}^{S-C}(\pi_{sw}) = \pi_{sw}\dfrac{r-\alpha_{cs}}{r-\alpha_{sw}} - (r-\alpha_{cs})C^{sw}$ for conversion from switchgrass to corn-soybean.

Above we have described various subsidies for supporting energy crop production currently used or proposed in many countries. They can be categorized into four types: (a) a constant annual subsidy, denoted by *f*; (b) a variable annual subsidy, which is a percentage of return, denoted by η; (c) an insurance policy, which guarantees a minimum annual return of $\underline{\pi}_{sw}$ from energy crops; and (d) a lump-sum payment made to the switchgrass grower either for the first year of growing switchgrass or for the reestablishment after a 10-year rotation, denoted by *s*. The constant subsidy and variable subsidy are abstracted from annual payments used in European countries and the United States, respectively. The insurance subsidy is a mimic of the proposed revenue-based commodity support program in FCEA (more details can refer to Cooper 2009) or possible insurance policy to be designed for energy crops proposed in EISA.

If farmers are risk-neutral and make decisions according to the ENPV rule, different forms of subsidies can give them the same incentive to convert land to energy crops as long as they have the same ENPV by equation (2). This implies that for a given governmental budget, these subsidies will perform the same in terms of attracting the land to grow energy crops. However, using the dynamic land conversion decision model developed above, we will show that ENPV-equivalent subsidies can affect the land conversion costs and instantaneous returns to competing land uses differently, causing the optimal land conversion rules will differ.

For each type of subsidy, the value functions need to satisfy the corresponding Bellman equations in the continuation region and the value matching and smooth pasting conditions on the boundaries of conversion. These conditions are summarized in table 2. Constant and variable subsidies will be added to the instantaneous return to switchgrass, which are $\pi_{sw} + f$ and $\pi_{sw} + \eta\pi_{sw}$, respectively. Under an insurance subsidy, the instantaneous payment in Bellman equation of V^{sw} is max $(\pi_{sw}, \underline{\pi}_{sw})$. The value-matching conditions and smooth pasting conditions for these subsidies are the same as (5) and (6). For a one-time cost-sharing subsidy, the Bellman equations for V^{i} are the same as (4), but the conversion cost C^{cs} is reduced by *s* in the value-matching condition for converting from corn-soybean to switchgrass. The smooth pasting condition is the same as (6).

The farmer's optimal land conversion rule under different forms of subsidy will be solved using the same projection method described in Appendix A. The subsidy levels need to be determined before the optimal land conversion model is solved. To make a meaningful comparison, we need to calibrate the subsidy parameters such that the ENPVs of governmental payments over a period are the same. The details about the calibration are presented in the next section.

Simulation of land use choice under different subsidy programs

Given the optimal land conversion rule, a representative corn-soybean grower will convert land to switchgrass when b^{c-s} is reached while a representative switchgrass grower will convert to corn-soybean when b^{s-c} is reached. With stochastic returns, we can compute the *ex ante* expected probability of a unit of corn-soybean land converting to switchgrass within a period of time. Previous real option literature (e.g. Leahy 1993; Pyndick and Dixit 1994) has show that in a competitive industry the optimal investment policy derived in a single-firm partial equilibrium setting happens to coincide with the optimal policy rule in a general equilibrium if all firms share the same risky process. Given a large number of firms in that industry, the *ex ante* probability of investment will also measure the fraction of available investment we can expect to be implemented (see example Metcalf and Hasett 1995, Sarkar 2003). In the case to predict the proportional land converted in to energy crops, we need to account for at least two more things. One is the crop price (or return) feedback effects caused by the land use change. Another is to model the farmers' heterogeneity. These may need a general stochastic dynamic model, which goes beyond the scope of our study. Nevertheless, the expected land conversion probability is indicative. We assume that governmental has a subsidy program whose goal is to cost effectively attract more land to grow energy crops. Given the same governmental budget, the higher probability of being in switchgrass that a subsidy program can engage, the more effective it is.

Given the optimal land conversion rules, we can simulate how the farmer responds to the changes of land use returns and calculate the governmental costs under different forms of subsidy. The simulation steps are illustrated by figure 2 and summarized in the following. Note that the steps in dotted rectangular are repeated.

First, we simulate N (=5000) sample paths of corn-soybean and switchgrass returns over 30 years according to the joint stochastic processes parameterized by values in table 1, denoted by $(\pi_{cs,n}(t),\ \pi_{sw,n}(t))$ for n=1,2,…,5000 and t=0,1,2,…30. This is done with the Econometric Toolbox in Matlab. The initial returns are assumed to be $\pi_{cs}(0) = \$119/acre$ at 2008 level and $\pi_{sw}(0) = \$133/acre$ at 2009 level for $\forall n$, which are the most recent data we can obtain. The initial land use is corn-soybean production.

Second, for each type of subsidy, we initially select a subsidy level and solve the land conversion decision rules.

Third, for each simulated path of corn-soybean and switchgrass returns, given critical land conversion boundaries under different types of subsidies, we can predict the land use assuming that the farmer acts according to the optimal land use decision rule. Each sample path of the two returns, $\{(\pi_{cs,n}(t), \pi_{sw,n}(t)), t = 1,...,30\}\ \forall n$, is compared with the conversion boundaries, $(b^{c-s}(\bullet),\ b^{s-c}(\bullet))$, to decide whether the land is kept in its current crop or should be converted to the alternative crop. For instance, in year 1, when the land is still in corn-soybean, the realized returns on a particular sample path, $(\pi_{cs,n}(t), \pi_{sw,n}(t))$, are compared with boundary b^{c-s}. If the realized returns are in the "no action zone" (e.g., if $\pi_{sw,n}(1) \le b^{c-s}(\pi_{cs,n}(1))$ according to the optimal decision rule), the land is kept in corn-soybean, and similar comparisons are made in year 2. If, on the other hand, the realized returns are in the "conversion zone" (i.e., if $\pi_{sw,n}(1) > b^{c-s}(\pi_{cs,n}(1))$), the land is converted to switchgrass, and in year 2, the realized returns $(\pi_{cs,n}(2), \pi_{sw,n}(2))$ will be compared with boundary b^{s-c} to decide whether the land should be converted into corn-soybean. We can also predict governmental payments based on the farmer's land use choice. Under constant subsidy, variable subsidy and insurance subsidy, the government pays the farmer f/acre, $\eta\pi_{sw}$/acre and max $(0, (\underline{\pi}_{sw} - \pi_{sw}))$/acre per year, respectively when the farmer is in switchgrass production. Under the cost-sharing subsidy, once the farmer converts land from corn-soybean to switchgrass[4] or reestablishes after ten years of being in switchgrass, the government will pay s/acre to the farmer. For each simulated path of corn-soybean and switchgrass returns, we calculate the NPVs of total governmental payments over 30 years for each type of subsidy. The mean and standard error of the discounted governmental costs over the N simulated paths of the joint returns can be obtained for each type of subsidy during a 30 year period.

Fourth, we calibrate the subsidies by repeating steps 1-3 so that the ENPVs of governmental costs at the end of 30 years under different subsidies are equalized, at a level of \$30/acre ($\pm$\$1). The calibrated subsidy parameters are presented in table 3. For each period we count the number of sample paths on which the land is in switchgrass. Dividing this number by N, we obtain the probability of land in switchgrass for each form of subsidy during a 30 year period.

Results

Critical land conversion boundaries under different forms of subsidies

In this section we present the effects of different subsidies on a representative farmer's optimal land conversion rule. In figure 3a-d, the solid curves are the critical boundaries b^{c-s} and b^{s-c} under the no subsidy base case. The dashed curves are conversion boundaries under the four different subsidies.

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[4] The government can require that a farmer has to stay in switchgrass for some minimum number of years to receive the cost-sharing subsidy; otherwise he has to pay a penalty. In the simulation, we impose that the farmer can receive the subsidy only if he did not convert from switchgrass to corn-soybean in the past five years.

A constant subsidy increases the instantaneous return to switchgrass. As expected, we can see from figure 3a that it lowers the conversion boundary from corn-soybean to switchgrass and raises the conversion boundary from switchgrass to corn-soybean. So it encourages farmers to convert to energy crops and discourages them from withdrawing.

Compared with a constant subsidy, a variable subsidy not only increases the switchgrass return but also its variability. This implies two opposite effects on the optimal land conversion decision: a higher return gives incentive to convert to switchgrass and a disincentive to withdraw land out of it, while more uncertainties will hold back converting to switchgrass and encourage converting out. Figure 3b shows that the return effect dominates the uncertainty effect on converting to switchgrass but the uncertainty effect dominates the return effect on converting out so that both b^{c-s} and b^{s-c} are lowered compared with no subsidy case. However, this is not always the case.

Farmers are assumed to receive the insurance subsidy only when the switchgrass return is lower than $\underline{\pi}_{sw}$, which is \$80/acre. The insurance subsidy generally lowers the conversion boundary from corn-soybean to switchgrass, but the effect is more dramatic when the corn-soybean return is lower than \$45/acre: farmers will convert to switchgrass even if its market return is zero since the subsidy can increase it to \$70/acre. Similarly, the subsidy raises the conversion boundary from switchgrass to corn-soybean much more when the switchgrass return is lower: for a switchgrass market return lower than \$50/acre the farmers will not convert to corn-soybean until the latter reaches at least \$145/acre (roughly). These effects gradually vanish when the switchgrass return goes beyond the insured level.

Different from the annual subsidies, a cost-sharing subsidy for switchgrass always lowers both direction land conversion boundaries (figure 3d). While reducing the conversion costs from corn-soybean to switchgrass (C^{cs}) makes the corn-soybean grower less reluctant to covert the land, it also has the indirect effect of making the switchgrass grower more prone to convert back to corn-soybean. This is because although the farmer currently growing switchgrass will not directly benefit from the subsidy for conversion to switchgrass, its existence reduces the expected cost of converting from corn-soybean back to switchgrass, thereby reducing the implied cost of switching back to corn-soybean. Thus it indirectly increases his incentive to convert land to corn-soybean. The direct effect of lowering C^{cs} is greater than the indirect effect. The reduction in C^{cs} lowers the boundary from corn-soybean to switchgrass more than the boundary from switchgrass to corn-soybean.

The probability of land in switchgrass under different forms of subsidies

The effects of a subsidy program on encouraging energy crop production can be illustrated more clearly using the probability of land in switchgrass over a 30 year period. By changing the optimal land conversion decision rule, the subsidy program will change the probability of land converted into energy crops as well as converting out. The lower the conversion boundary from corn-soybean to switchgrass, the more likely the realized returns can reach the boundary, so that the farmer will convert to switchgrass. Conversely, the lower the conversion boundary from switchgrass to corn-soybean, the more likely the realizations of the returns can reach the boundary, so that the farmer will convert out of switchgrass.

Figure 4 shows the expected probabilities of a unit corn-soybean land in switchgrass over a 30 year period under the no subsidy case and the four single subsidy program, given that the expected governmental cost is uniformly \$30/acre at the end of 30 years. The cumulative probability is not monotonically increasing over the years because the farmer can optimally convert back to corn-soybean when its return is high enough and reach the conversion boundary b^{s-c}. We first examine the case without subsidy, indicated by the solid curve in figure 4. At the beginning, the probability of land converted into switchgrass increases over years and peaks at 0.19 in year 9. However, the switchgrass return also has a higher level of uncertainty, and eventually land in switchgrass is likely to be converted back to corn-soybean. At the end of the 30 years, the probability of land in switchgrass is about 0.1. The average probability of land in switchgrass over 30 years is 0.14.

A constant subsidy lowers b^{c-s} and raises b^{s-c}, implying that it is easier to convert into switchgrass and harder to convert out. The conversion pattern over time is similar to the no subsidy case but the probability of land in swtichgrass peaks at 0.23 and stabilizes at 0.13, increased by 0.04 and 0.03 compared with the no subsidy case. The average probability over all 30 years is also increased from 0.14 to 0.18. In contrast, the variable subsidy and cost-sharing subsidy lower both b^{c-s} and b^{s-c} (although for different reasons as we discussed above), implying that it is easier to convert into switchgrass as well as to convert out. These two subsidy types raise the peak probability of land in switchgrass to 0.2 and 0.24, respectively, but barely change where it stabilizes. The variable subsidy increases the average probability of land in switchgrass over years from 0.14 to 0.15 and the cost-sharing subsidy increases it to 0.17.

When both of the corn-soybean and switchgrass returns are low, the insurance subsidy effectively makes switchgrass the dominant choice. Once the return of corn-soybean falls below $45/acre, the land will be converted to switchgrass and will not be converted out until the corn-soybean return bounces back to at least $145/acre. So the insurance subsidy increases the probability of land in switchgrass the most, peaking at 0.24 and stabilizing at 0.2. The average probability over all 30 years is 0.2.

The Change and Variation of Governmental Costs over Years

Each subsidy program is calibrated such that it will incur the same expected governmental cost at the end of 30 years. However, these costs may change from year to year. This information is interesting because the government may prefer a policy program that has a stable stream of expenditures. Figure 5a shows the mean NPV of governmental costs under each subsidy over 30 years. Since the cost-sharing subsidy is a relative large one-time payment and more conversion to switchgrass happen in the first several years, its expenditure grows faster in the beginning years (until year 6), slows down until intermediate period and stabilizes after year 15. The other three subsidies are annual payments, which increase steadily over the years.

We have assumed the risk-neutrality of government and an *ex ante* budget constraint and compared the cost-effectiveness of different subsidies. However, the performance of different subsidies could change if the government is risk averse, or has an *ex post* budget or both. Then less variability of the governmental expenditures will be more desirable. Figure 5b shows the simulated standard errors of the NPV of the governmental costs for each subsidy program over the 30 years. The standard error of the cost-sharing subsidy payment rises rapidly in the first 5 years and becomes steady at $40/acre since then. The standard error of the constant subsidy payment keeps rising steadily to 46/acre at the end of 30 years. The distributions of other two subsidy payments are much more heavy-tailed. The simulated standard error is $165/acre and $80/acre, or 5.5 and 2.7 times of the mean under the variable subsidy payment and the insurance subsidy payment, respectively.

The Effects of Combining Cost-sharing Subsidy with Other Types of Subsidies

In addition to considering the program implementing a single subsidy, we also evaluate the effectiveness of combining the lump-sum cost-sharing subsidy with other three types of annual subsidy, as often occurs in practice. For example, as we discussed above, Irish farmers can receive a subsidy up to half of establishment costs as well as a constant subsidy of $70/acre for planting willow and miscanthus, while U.S. farmers can receive a subsidy up to 75% of the establishment costs and a 2-year variable subsidy that matches the biorefiner's payment for any eligible energy crop.

Again we compare the three forms of combined subsidies among themselves and with their single form subsidy counterpart by how they change the expected probability of a unit of corn-soybean land converting to switchgrass. The simulation is performed given an expected governmental cost at $65/acre. The calibrated subsidy levels are presented in table 4. First we can examine the relative performance of the three combined subsidies. Figures 6 a-c show that consistent with the relative performance of the single subsidy forms, subsidizing the establishment costs and insuring a minimum return will result in the highest probability of land in switchgrass, which peaks at 0.3 and stabilizes at 0.2 at the end of 30 years and averages at 0.24. A constant subsidy together with a cost-sharing subsidy has 0.26 probability of land in switchgrass at the peak and 0.18 at the end of 30 years, averaging 0.2. A variable subsidy together with a cost-sharing subsidy will rank lowest, having probability of 0.22 for land growing switchgrass at peak and 0.11 at the end of 30 years and averaging 0.16. The average probability over years change little compared to the single forms, but single form subsidies have smaller variances. Compared with their single subsidy counterpart, the combined forms slightly increase the probability of land in switchgrass in the intermediate period but reduce it toward the latter part of a 30 year time horizon. This can be explained by the dual effects of the cost-sharing subsidy on land conversion: it has a positive effect on the expected rate of converting land to switchgrass by lowering the conversion boundary b^{c-s} more than the annual subsidies but also has a negative effect by inducing land converting out later since it lowers the conversion boundary b^{s-c}.

Conclusion

This study examines the design of agricultural subsidy programs that aim to encourage desirable land use using a real options framework that reflects the following features: (a) the dynamic characteristics of land conversion; (b) the sunk costs and future return uncertainties associated with land conversion; and (c) flexibility in an optimizing, representative farmer's land use decisions. Results show that failure to consider these factors can lead to misleading conclusions. Although the levels of different subsidy forms were selected to be ENPV-equivalent, they are not equally cost-effective.

Using energy crop production as an example, we compare three annual subsidies and one lump-sum subsidy that have the same expected governmental costs. The insurance subsidy results in the highest expected probability of land being converted to energy crops (switchgrass), followed by the constant subsidy. Although the cost-sharing subsidy and the variable subsidy have the positive effect of encouraging land conversion to switchgrass, they also have the negative effect of discouraging land from staying in that land use. The two effects cancel each other out and result in an increase in the predicted probability of land in switchgrass in the intermediate period but a drop back to the no-subsidy level at the end of 30 years. The relative performance of combing cost-sharing subsidy with other annual subsidies is consistent with comparison of single subsidies.

The results presented in this paper suggest that the existing U.S. energy crop subsidy system, which is a variable subsidy combined with a cost-sharing subsidy, may not be the most cost-effective. Greater cost-effectiveness of the insurance subsidy highlights the research needs for how to reduce the uncertainties of the returns to energy crops. Taheripour and Tyner (2008) propose a subsidy that is inversely related with the oil price[5] in order to reduce the volatility of energy crop prices. Compared with the government providing an insurance policy, the long-term contract between energy crop growers and biorefiners may serve as a better mechanism considering the possible transaction costs involved in the former.

There is a caveat in evaluating the performance of cost-sharing subsidy based on our results. We only consider the cost-effectiveness of a subsidy, i.e., the ability to convert land to switchgrass given the same governmental expenditures. But there are other factors that justify the cost-sharing subsidy, one of which is the farmer's liquidity constraint. Numerous studies show farmers are concerned about the large up-front costs of establishing the energy crops (e.g. Sherrington, Bartley and Moran 2008; Bocqueho and

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[5] They call it the variable subsidy, which clearly is different from the one in our paper.

Jacquet 2010). A cost-sharing subsidy can relax this constraint and thus reduce the adoption barriers.

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Table 1. Parameters for Solving Optimal Land Conversion Rule without Subsidies

Land conversion model parameters	**Notation and Value**	
Discount factor	r	0.08
Drift rate of corn-soy return	u_{cs}	0.04
Drift rate of switchgrass return	u_{sw}	0.04
Variance parameter of corn-soy return	σ_{cs}	0.29
Variance parameter of switchgrass return	σ_{sw}	0.62
Land conversion cost from corn-soy to switchgrass	C^{cs}	$139/acre
Land conversion cost from switchgrass to corn-soy	C^{sw}	$47/acre

Table 2. Land Conversion Optimality under Different Subsidies

	Bellman equations	Value matching conditions	Smooth pasting conditions
Cost-sharing subsidy	Same as (4)	Same as (5) for i=cs ; for i = sw $V^{cs}(\pi_{cs},\pi_{sw}) = V^{sw}(\pi_{cs},\pi_{sw}) - (C^{cs} - s)$ when $\pi_{sw} = \pi^*_{sw}$	Same as (6)
Constant subsidy	Same as (4) for i=cs ; for i = sw $rV^{sw}(\pi_{cs},\pi_{sw}) = \pi_{sw} + f + \sum \alpha_i \pi_i V^i_{\pi_i} + \sum 1/2\sigma_i^2 \pi_i^2 V^i_{\pi_i \pi_i} + \rho\sigma_1\sigma_2\pi_{cs}\pi_{sw}V^i_{\pi_{cs}\pi_{sw}}$	Same as (5)	Same as (6)
Variable subsidy	Same as (4) for i=cs for i = sw $rV^{sw}(\pi_{cs},\pi_{sw}) = (1+\eta)\pi_{sw} + \sum \alpha_i \pi_i V^i_{\pi_i} + \sum 1/2\sigma_i^2 \pi_i^2 V^i_{\pi_i \pi_i} + \rho\sigma_1\sigma_2\pi_{cs}\pi_{sw}V^i_{\pi_{cs}\pi_{sw}}$	Same as (5)	Same as (6)
Insurance Subsidy	Same as (4) for i=cs for i = sw $rV^{sw}(\pi_{cs},\pi_{sw}) = \min(\pi_{sw},\underline{\pi}_{sw}) + \sum \alpha_i \pi_i V^i_{\pi_i} + \sum 1/2\sigma_i^2 \pi_i^2 V^i_{\pi_i} + \rho\sigma_1\sigma_2\pi_{cs}\pi_{sw}V^i_{\pi_{cs}\pi_{sw}}$	Same as (5)	Same as (6)

Table 3. Parameters for Policy Simulation: Single Subsidy

Subsidy form	**Subsidy level**
Constant subsidy	$ 14.5/acre
Variable subsidy	2%
Insurance subsidy	$ 80/acre
Cost-sharing subsidy	$ 110/acre
Governmental costs	*$30/acre*

Table 4. Parameters for Policy Simulation: Single Subsidy vs. Combined Subsidy

	Combined form	**Single form**
Cost-sharing subsidy	70/acre	
Constant subsidy	$ 19/acre	$29/acre
Variable subsidy	3%	4%
Insurance subsidy	$ 80/acre	$111/acre
Governmental costs	*$65/acre*	

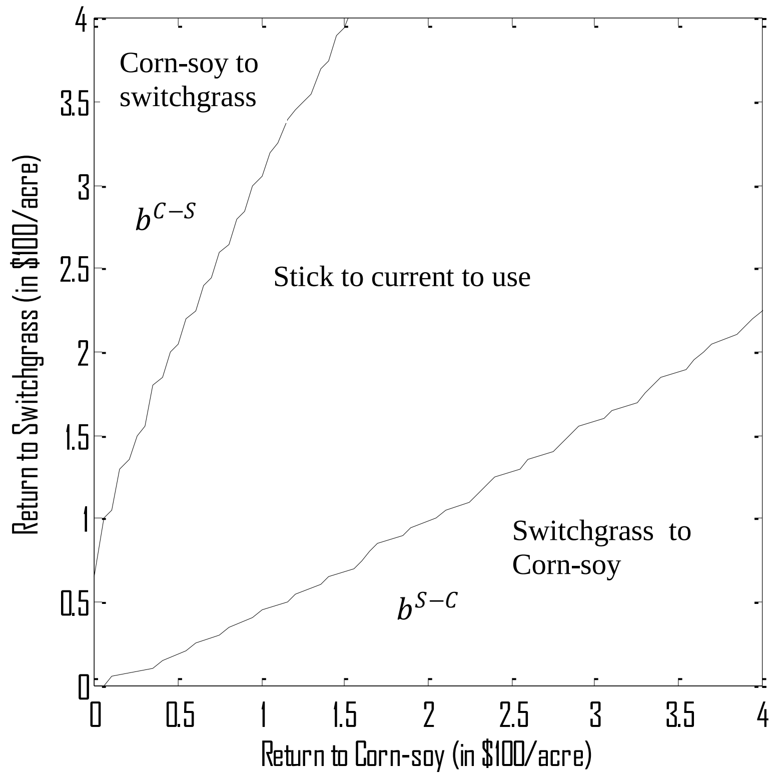


Figure 1. Optimal Land Conversion Rule: No Subsidy

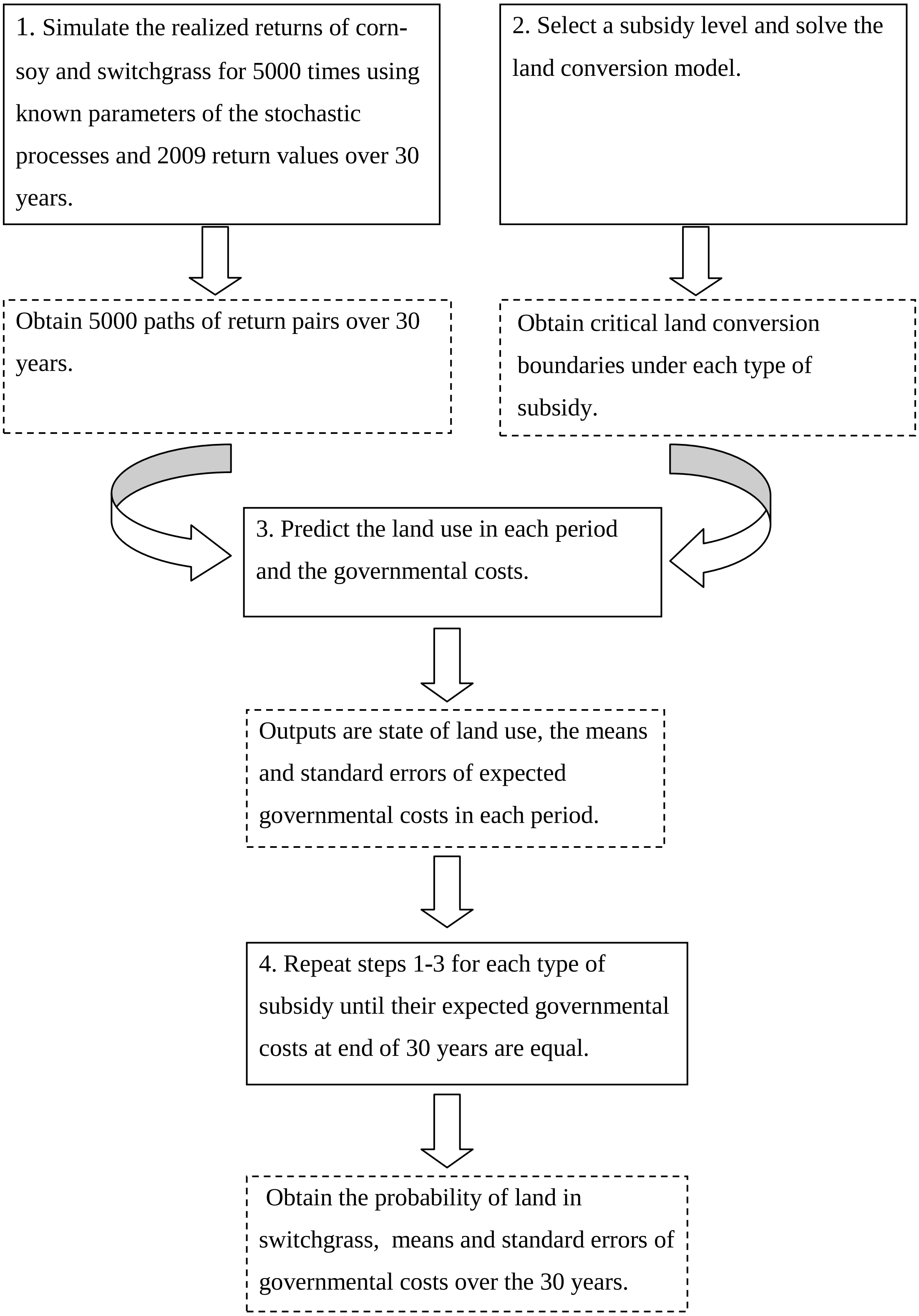
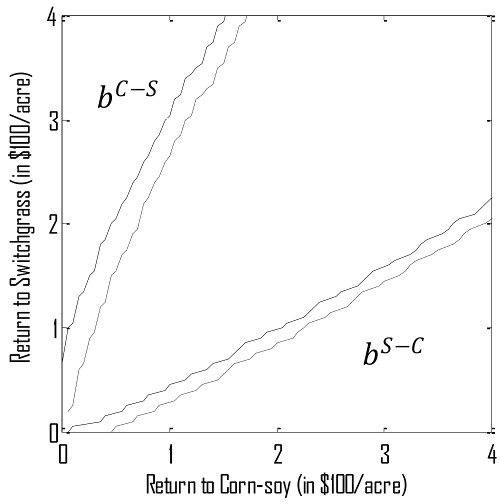
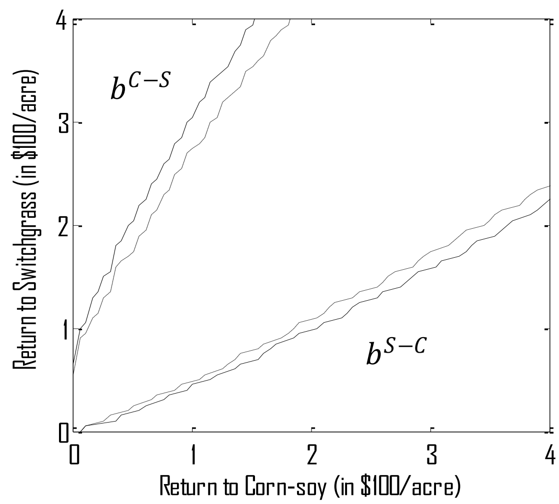


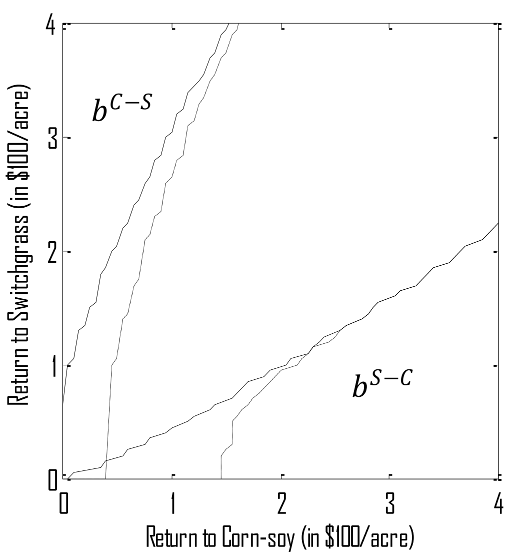
Figure 2. Land Conversion Simulation Steps



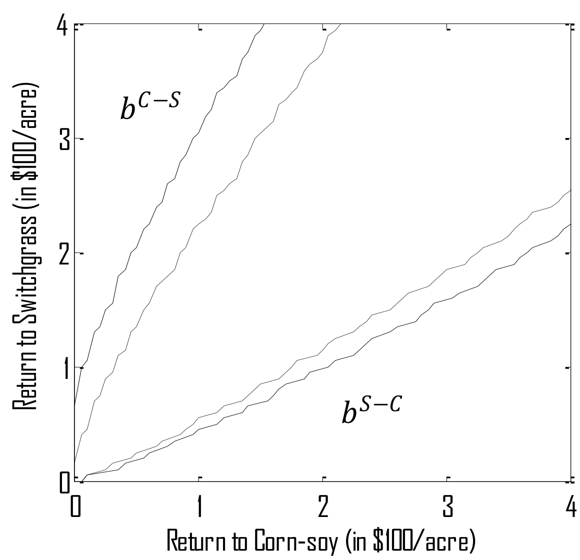
3a. Constant subsidy



3b. Variable Subsidy



3c. Insurance Subsidy



3d. Cost-sharing subsidy

Figure 3. Optimal Land Conversion Rule under Different Subsidies

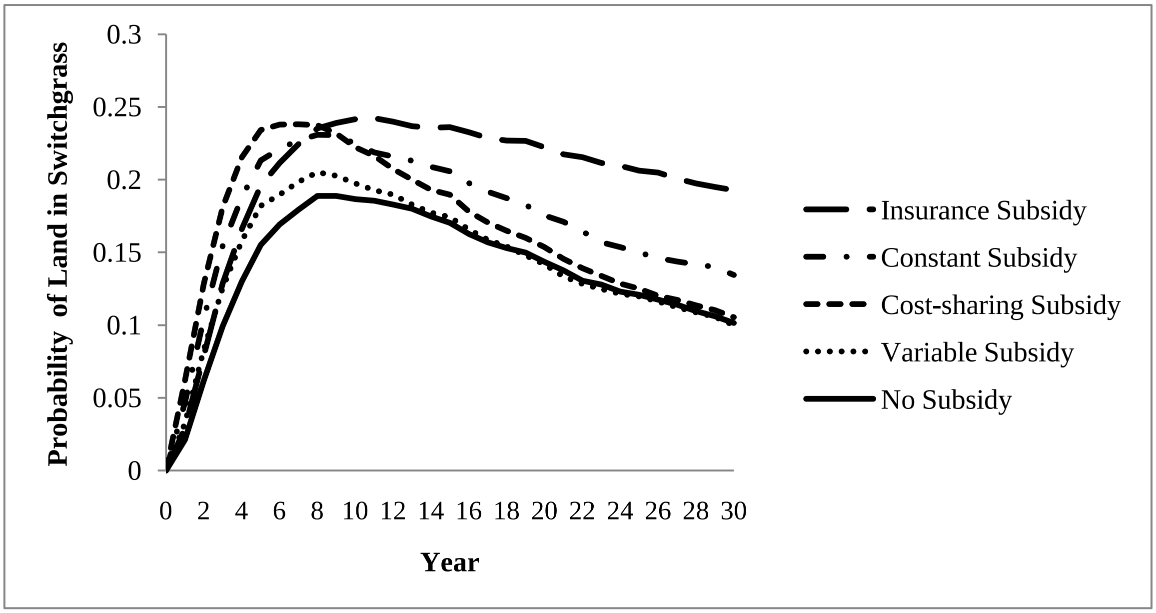


Figure 4. Probability of Land in Switchgrass: Comparison of Single Subsidy (Expected NPV of Governmental Costs=$30/acre)

Note: The average probability of years: 0.2 for the insurance subsidy, 0.18 for the constant subsidy, 0.17 for the cost-sharing subsidy, 0.15 for the variable subsidy, and 0.14 for the no subsidy case.

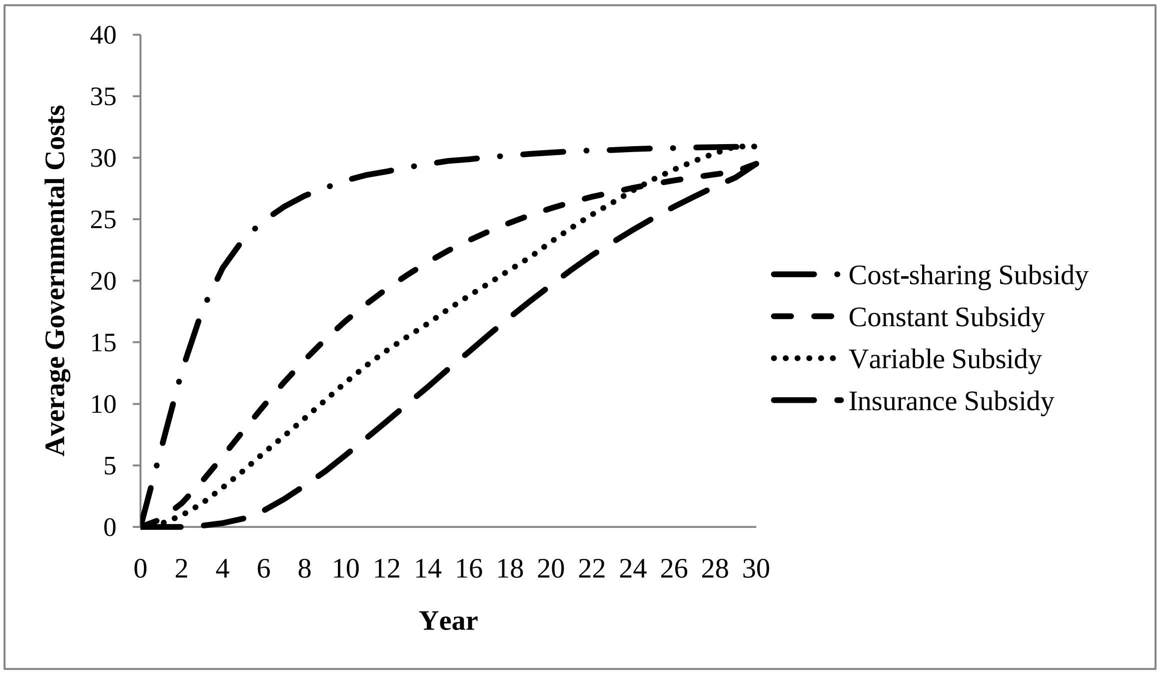


Figure 5a. Mean NPV of Governmental Costs over Years

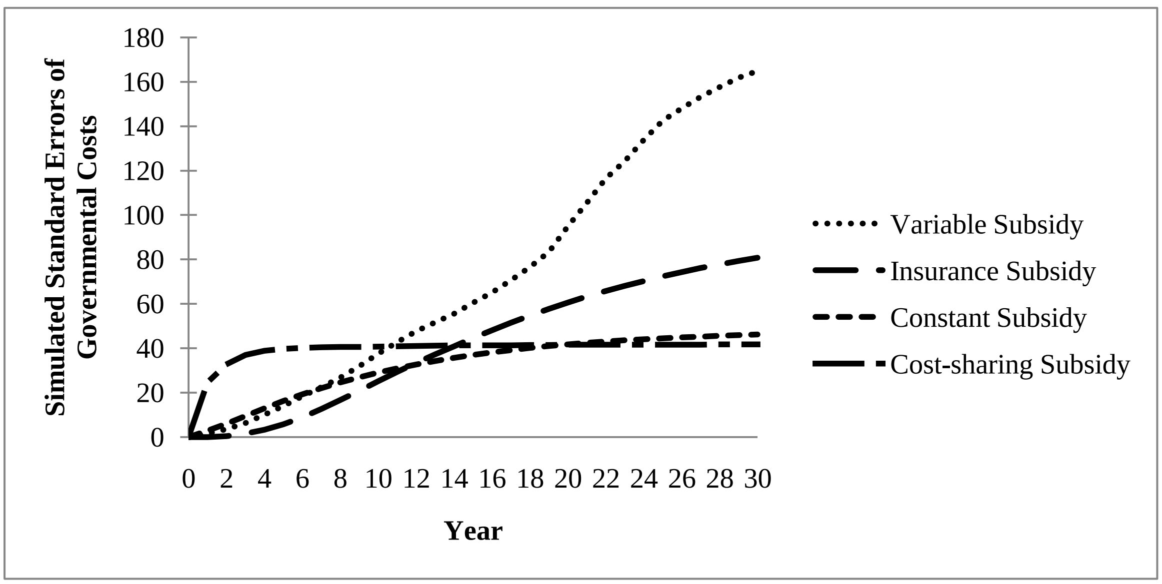
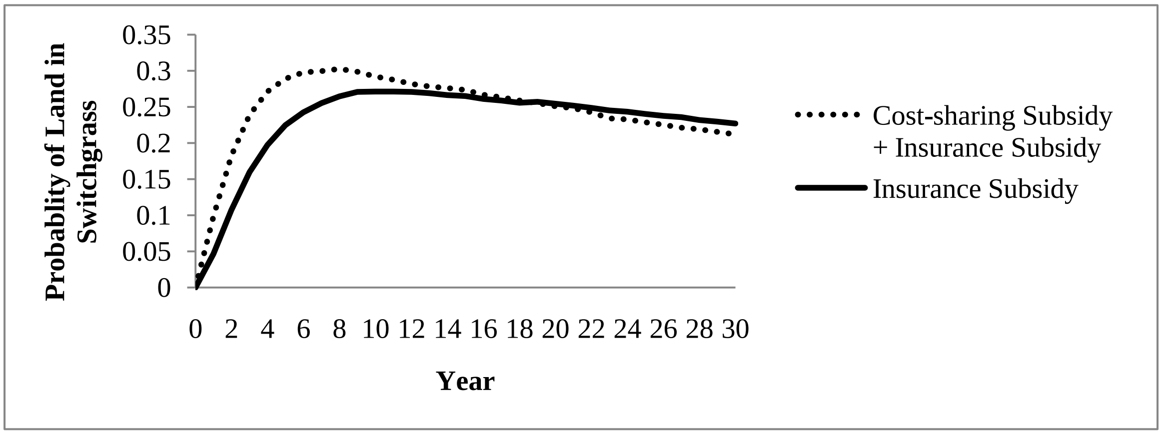
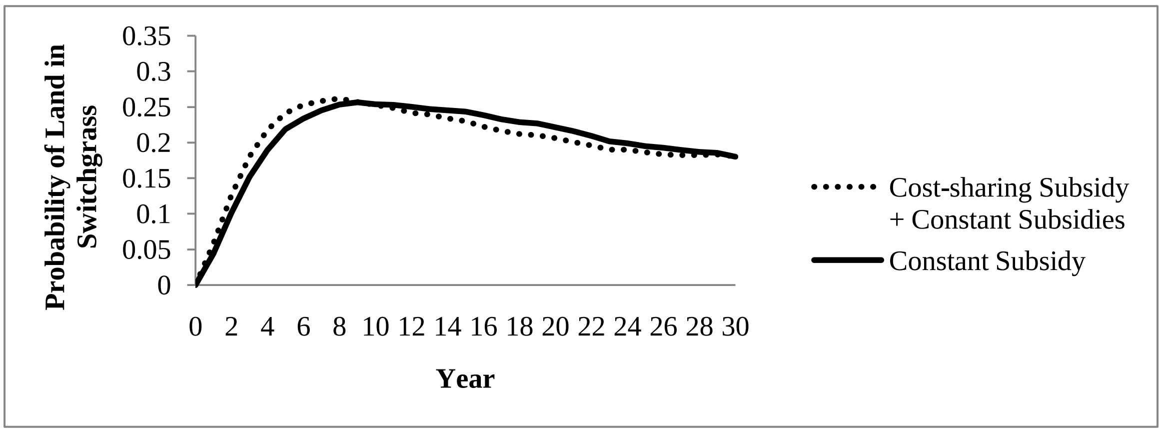


Figure 5b. Standard Error of NPV of Governmental Costs over Years



a



b

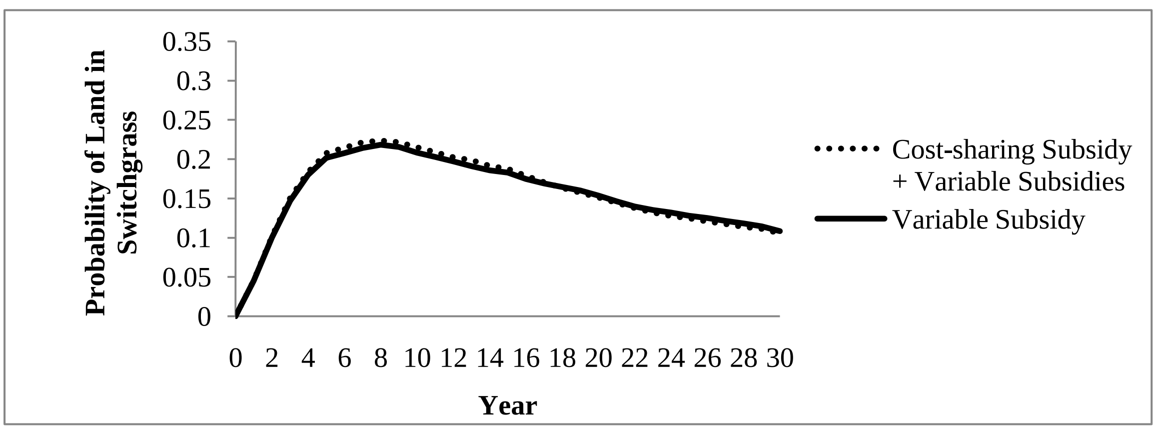


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Figure 6. Effect of combining cost-sharing subsidy with annual subsidy (expected NPV of governmental costs=$65/acre)